CCD cameras and Spacewire interfaces for HERSCHEL/SCORE suborbital mission

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ORIGINAL ARTICLE

CCD cameras and Spacewire interfaces for HERSCHEL/SCORE suborbital mission

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Abstract The HERSCHEL/SCORE is a suborbital mission which will observe the solar corona in UV and in visible light for measurements of solar corona. The coronagraph for such observation is an Italian instrument and, in particular, the CCD camera detectors are developed at the XUVLab of the Department of Astronomy and Space Science of Florence University. Such detectors communicate with the on-board computer by means the IEEE1355 Spacewire standard interface (developed in our laboratories) and implement a lot of smart and custom procedures for imaging.

The main innovation of SCORE coronagraph is the first use in space of a variable retarder plate based on liquid crystals and the optical design capable of simultaneous observation in UV and Visible light.

Keywords SMCSlite communication controller · 4 Mb FIFO memory · FIFO controller · Local controller · LVDS driver/receiver

1 Introduction

SCORE (Sounding CORona Experiment) has been included in the HERSCHEL (HElium Resonant Scattering in the Corona and HELiosphere) sounding rocket payload. HERSCHEL is conceived as a NASA Sounding Rocket Program providing new EUV/UV and visible-light coronal observations to directly measure and to characterize in detail the properties of the two most abundant elements, hydrogen and helium. In particular, HERSCHEL will be able to provide:

- The first global images of the HeII corona
- The first global EUV images of the corona for the two most abundant elements, H and He
- The first maps of He abundance in the corona
- The first global maps of the solar wind outflow (H^0 and He^+ outflow)
- Polarimetric measurement in the visible of the solar extended corona
- A proof-of-principle for the SCORE.

The HERSCHEL payload consists of the HERSCHEL EUV Imaging Telescope (HEIT), similar to the SOHO/EIT instrument, the HERSCHEL EUV Coronagraph (HECOR) and the SCORE coronagraph. The latter is a reflecting coronagraph designed to get images of the full corona from 1.2 to 3 $R_\odot$ in the HI Lyα line at 121.6 nm, in the HeII Lyα line at 30.4 nm and to measure polarimetric brightness in the visible spectral region. The coronagraph is externally occulted and its optical design is based on novel solutions to improve the stray light rejection and to use the same optical components to focus the radiation in the selected wavelength bands.

In order to measure the coronal polarized radiation in the visible band, the SCORE coronagraph is equipped with a novel polarimetric group: which implements a LC (Liquid Crystal) retarder plate.

SCORE is under development and is almost ready for ground-based characterization tests. These tests will provide information on the telescope multilayer mirrors, the stray light rejection, and the low noise CCD cameras.

The detectors for the SCORE coronagraph are two CCD cameras provided by the XUV Laboratory team of the Dept.

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of Astronomy and Space Science of the University of Florence. The cameras will be developed starting from the laboratory prototype which was used for ground applications, following the rocket specifications, and optimized to operate the selected sensor.

Each camera will operate at a pixel rate of 300 kHz and will satisfy requirements, such as very low readout noise, high quantum efficiency, wide dynamic range, good linearity and uniformity.

Moreover, a good level of versatility is a desirable feature that allows:

- an arbitrary pattern generation of the digital clock waveforms, to operate our camera with a variety of CCDs and to fine-tune the selected sensor
- satisfying the mission requirements like the data transfer protocols between the interface and the main computer, as well as limitations on weight, power, size: a customizable camera can be modified while a commercial camera is usually not
- generating an additional synchronous trigger to drive the polarimeter during the image acquisition.

Both the CCD cameras are provided with a Spacewire (SpW) interface which is a standard ESA/NASA protocol for data transmission in space applications. The SpW interfaces and CCD cameras have an high level of automation due to the small observing time (only $\sim$300 s); since in such brief observational time is not possible to send commands from ground station, the electronics must recognize errors and must recover them.

2 SCORE instrument

The SCORE coronagraph is an external occulted off-axis Gregorian telescope, capable of simultaneous images acquisition in visible light (VL) and UV narrowband (UVL).

SCORE coronagraph will observe in VL and H Lyα simultaneously using a magnesium fluoride filter, then a mechanism will swap this filter with another one of Aluminum to observe only UVL (HeII Lyα). Then the filters will be swapped again to acquire H and VL images once and again.

The detectors of SCORE coronagraph are two CCD cameras, one for VL images (VLD) and one for UVL images (UVD); both CCD cameras are provided by XUVLab.

The VLD includes a polarimetric group (KPol) to measure the polarized brightness of solar corona. The main innovation of this polarimeter is a Meadowlark Liquid Crystal Variable Retarder (LCVR).

3 Kpol and LCVR

KPol is a liquid crystal-based polarimeter. The key optical element of the KPol is the LCVR. This electro-optical device uses nematic liquid crystal materials whose birefringence can be controlled by changing the applied bias voltage. Most of current polarimeters are based on fixed linear polarizers and rotating retarders, but more efficient polarimetric systems use electro-optical modulators instead of mechanical rotating elements.

Liquid-crystal devices are optically anisotropic media that act locally as a uniaxial retardation plate and exhibit optical birefringence.

They produce different polarization states depending on the external applied voltage and therefore can also be used in polarimeters.

The schematic optical layout of the KPol consists of a fixed $\lambda/4$ retarder with the fast axis aligned to the 0° axis of the system, a LCVR with the fast axis at 45° and a linear polarizer with its transmission axis at 0°. A narrow band color filter, centred at 620 nm, is placed in front of the polarimetric complex and selects the polarimeter bandpass (Pancrazzi 2006; Gherardi and Gori 2004).

4 CCD cameras

The SCORE coronagraph has two channels, the UV channel and the Visible Light channel, each one with a camera detector:

1. Visible Light Detector (VLD) for solar corona polarized brightness observations
2. UltraViolet Detector (UVD) for narrowband H Lyα 121.6 nm and HeII at 30.4 nm.

The VLD is an E2V CCD47-20 1024×1024, frame transfer, operating in 2×2 binning mode. It has a 16-bit dynamic range and produces 4 Mb images.

The UVD consists of a MCP coupled to a CCD. The CCD is the E2V CCD42-40. UVD will acquire both He and H images, by selecting different filter configurations in the telescope.

The images acquired by both CCD are readout at 300 kpx/s and stored into an internal FIFO memory, one per each detector, in $\sim$1.7 s (VLD); then they are ready for download to the PC.

Each camera is controlled by its own electronics, which is able to provide all signals for the detector (bias voltages, clocks, signals for the polarizer), and to manage the acquisition sequence.

SCORE CCD electronics consists of the following PCB boards: Power Supplies and Bias Generator (PS), Peltier Power Supplies (PPS) and shutter controller (VLD only), Sequencer (SEQ) and Clock Driver, CCD and Preamplifier (PA), Correlated Double Sampler (CDS) and ADC, SpaceWire interface (SpW), LCVR (Liquid Crystal Variable Retarder) controller (LCVRC) (*VLD only*) (Gherardi 2002).

While all boards are hosted inside the CCD camera case, the LCVRC is a stand-alone board hosted in a dedicated case (Polarimeter Electronics Box—PEB) near the KPol polarimeter (Rossi 2005; Drouillard et al. 2005).

SCORE has two observing modes: UV HI + VL pB and UV HeII.

A folding mirror, driven by a folding mirror mechanism (FMM), is used to switch between the two modes.

5 Spacewire interface

The CCD camera, the LCVR controller and the Peltier power supply need a link to the on-board computer. It sends to the cameras and LCVRC commands to power-up, to start acquisition, handshake, housekeeping of temperature and commands to manage recovery following failures.

The rocket onboard computer is provided with Spacewire interface, that is a standard communication protocol (hardware and software) adopted by ESA and NASA.

Since this kind of interface is still rare, since the application is for space and the requirements for the interface are very specific, we developed a custom Spacewire interface.

A fully compliance with SpaceWire (ECSS E-50-12A) is not required for the link; the revised IEEE-1355 DS/DE sub-standard with LVDS signalling, is implemented: this guarantees compatibility with SpaceWire standard. This is achieved by using the SMCSlite device.

A buffer for an image of 4 Mb is required; the image is received from the ADC at a 300 kHz and is buffered in case of onboard computer is busy.

An image is transmitted via the IEEE-1355 link packed with some additional information, placed in the header (Response time 2005).

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